REPORT DOCUMENTATION PAGE

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03-02-2016	Final Report	10-Sep-2012 - 9-Sep-2014

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Final Report: Strongly Correlated Topological Insulators

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5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

6. AUTHORS
B. A. Bernevig, B Estienne, N. Regnault

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES
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14. ABSTRACT
In the past year, the grant was used for work in the field of topological phases, with emphasis on finding new many-body states of matter, new many-body methods to analyze them and new phenomena that would happen in the presence of interactions on the surface of topological insulators. In the past 3 years, we have started a new direction, that of fractional topological insulators. These are materials in which a topologically nontrivial quasi-flat band is fractionally filled and then subject to strong interactions.

15. SUBJECT TERMS
Condensed Matter, Topological Phases of Matter

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
UU	UU	UU	UU		B. Andrei Bernevig
					19b. TELEPHONE NUMBER
					609-258-1594

Report Title

Final Report: Strongly Correlated Topological Insulators

ABSTRACT

In the past year, the grant was used for work in the field of topological phases, with emphasis on finding new many-body states of matter, new many-body methods to analyze them and new phenomena that would happen in the presence of interactions on the surface of topological insulators. In the past 3 years, we have started a new direction, that of fractional topological insulators. These are materials in which a topologically nontrivial quasi-flat band is fractionally filled and then subject to strong interactions.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received	Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received	Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received		Paper
02/03/2016	6.00	Nicolas Regnault, T. Senthil. Microscopic model for the boson integer quantum Hall effect, PHYSICAL REVIEW B (05 2013)
10/01/2013	1.00	S. Nadj-Perge, I. K. Drozdov, B. A. Bernevig, Ali Yazdani. Majorana fermions in chains of magnetic atoms on a superconductor, Physical Review B (accepted) (10 2012)
10/01/2013	2.00	B. Estienne, Z. Papic, N. Regnault, B. A. Bernevig. Matrix product states for trial quantum Hall states, Phys Rev B (11 2012)
10/01/2013	3.00	Yang-Le Wu, N. Regnault, B. Andrei Bernevig. Bloch Model Wavefunctions and Pseudopotentials for All Fractional Chern Insulators, Phys Rev B (10 2012)
10/01/2013	4.00	Simon C. Davenport, Eddy Ardonne, Nicolas Regnault, Steven H. Simon. Spin-singlet Gaffnian wave function for fractional quantum Hall systems, Phys Rev B (12 2012)
10/01/2013	5.00	E. Dobardzic, M.V. Milovanovic, N. Regnault. On the geometrical description of fractional Chern insulators based on static structure factor calculations, Phys Rev B (04 2013)

TOTAL: **6**

Number of Manuscripts:

Books

Received	Book

TOTAL:

Received	Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Blavatnik Award, September 2012
David and Lucile Packard Fellowship, October 2011

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Yangle Wu	0.20	
FTE Equivalent:	**0.20**	
Total Number:	**1**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
B Estienne	0.30
FTE Equivalent:	**0.30**
Total Number:	**1**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Bogdan Andrei Bernevig	0.15	
Nicolas Regnault	0.15	
FTE Equivalent:	**0.30**	
Total Number:	**2**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period:	0.00
The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:......	0.00
The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:......	0.00
Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):......	0.00
Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:......	0.00
The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense	0.00
The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:......	0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Yangle Wu

Total Number: 1

Names of other research staff

NAME	PERCENT_SUPPORTED

FTE Equivalent:

Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Scientific Progress and Accomplishments.
In the past year, the grant was used for work in the field of topological phases, with emphasis on finding new many-body states of matter, new many-body methods to analyze them and new phenomena that would happen in the presence of interactions on the surface of topological insulators. In the past 3 years, we have started a new direction, that of fractional topological insulators. These are materials in which a topologically nontrivial quasi-flat band is fractionally filled and then subject to strong interactions. The electrons then re-organize themselves into a gapped many-body state which resembles the Fractional Quantum Hall effect, but unlike it, can potentially exist in more than 2-dimensional quantum wells. By using a mix of numerical and analytical techniques, we have obtained a new set of many-body wavefunctions for these “Fractional Topological Insulators” on a lattice which generalize the Laughlin, Moore-Read and Read-Rezayi series of Fractional Quantum Hall states. We are also in the process of proposing realistic realizations of these phases in electronic and cold atomic systems on kagome lattices with nontrivial band topology. All these states are likely to have very new and intricate surface physics.
Another direction we have explored focuses on breaking the barriers of numerical simulations for interacting topological phases. We have shown using a new representation (a matrix product state) that we can approximate several model wavefunctions in a very efficient and control way thanks to their conformal field theory representation. Armed with this, we have been able to compute a series of universal quantities of these states such as topological spin, Chern numbers, and edge exponents. We hope that these new progresses could lead to simulations involving a number of particles an order of magnitude greater than previously achieved, and could help discover new fractional phases in 3-dimensional systems.
Since September 2012 I have also worked on research involving topological superconducting states of matter, with focus on Majorana modes in topological superconductors and crystalline topological insulators. Along with Ali Yazdani, we proposed a scheme to create Majorana fermions at the ends of a wire of magnetic atoms exhibiting a spin helix, placed on top of an s-wave superconductor.
?This system is currently being built in experiments. Magnetic atoms are deposited on anisotropic surfaces and naturally grow in wires. Their spins will naturally have a helical form. Depending on the helix pitch, the system can exhibit kitaev majorana wire behavior. The majoranas can be seen as zero-bias peaks at the end of the wire.

Technology Transfer

Scientific Progress and Accomplishments.

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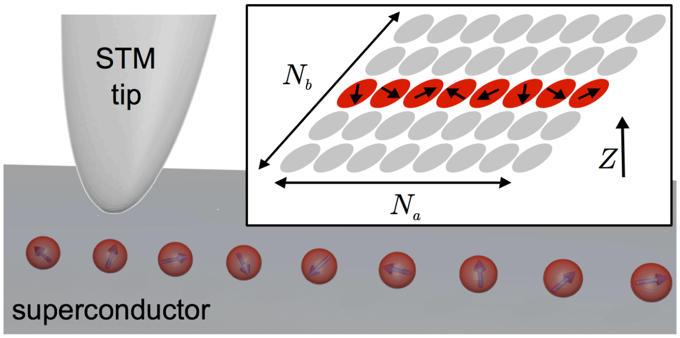

This system is currently being built in experiments. Magnetic atoms are deposited on anisotropic surfaces and naturally grow in wires. Their spins will naturally have a helical form. Depending on the helix pitch, the system can exhibit kitaev majorana wire behavior. The majoranas can be seen as zero-bias peaks at the end of the wire.

Published Work Acknowledging ARMY ARO Grant

Majorana fermions in chains of magnetic atoms on a superconductor
S. Nadj-Perge, I. K. Drozdov, B. A. Bernevig, Ali Yazdani
Comments: 5 pages, 5 figures + supplementary
Journal-ref: Phys. Rev. B 88, 020407(R) (2013)

Matrix Product States for Trial Quantum Hall States
B. Estienne, Z. Papic, N. Regnault, B. A. Bernevig
Comments: 5 pages, 1 figure, published version
Journal-ref: Phys. Rev. B 87, 161112(R) (2013)

Bloch Model Wavefunctions and Pseudopotentials for All Fractional Chern Insulators
Yang-Le Wu, N. Regnault, B. Andrei Bernevig
Comments: 6+epsilon pages, 2 figures. Published version. Added a discussion of the emergent particle-hole symmetry in a Chern band
Journal-ref: Phys. Rev. Lett. 110, 106802 (2013)

Microscopic model for the boson integer quantum Hall effect
N. Regnault, T. Senthil

Spin-singlet Gaffnian wave function for fractional quantum Hall systems
Simon C. Davenport, Eddy Ardonne, Nicolas Regnault, Steven H. Simon
Comments: 15 pages, 2 figures.
Journal-ref: Phys. Rev. B 87, 045310, (2013)

On the geometrical description of fractional Chern insulators based on static structure factor calculations
E. Dobardzic, M.V. Milovanovic, N. Regnault
Phys. Rev. B 88, 115117 (2013)